East Kootenay Trench
Stand Reconstruction and Fire History
Study Workplan

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1.0 INTRODUCTION

This workplan has been developed in fulfillment of Minor Services Contract No. 160356: East Kootenay Trench Stand Reconstruction. This study is comprised of a study site identification component, completed in September 1996, and the following workplan. Contained in the workplan are instructions for reconstructing stand structure and fire history through the life of the stands identified in the study site analysis. The workplan includes the following sections: introduction, background, objectives, candidate site ranking, methods (both field and laboratory), resources required, summary report, work schedule, and literature cited.

2.0 BACKGROUND

Throughout many areas of western North America, the condition of forests is seen as "unhealthy" (Quigley 1992; Mutch et al. 1993; Kolb et al. 1994; Skovlin and Thomas 1995; Tanaka et al. 1995; Steele et al. 1996). The symptoms of the problem are large stands of dead and dying trees, a steady reduction in local and regional biological diversity, and an increasing threat to public and private property from large-scale wildfire (Mutch et al. 1993). The most visually apparent cause of the problem is attributed to epidemics of insects, such as bark beetles and defoliators, and fungi, such as root and stem pathogens (Johnson et al. 1994). Abiotic factors such as drought and wind also play a role in creating the appearance of a forest health problem (Johnson et al. 1994). The underlying cause has been an alteration of the natural fire regime (Quigley 1992; Mutch et al. 1993; Johnson et al. 1994; Kolb et al. 1994; Mutch 1994; Tanaka et al. 1995; Arno 1996a; Steele et al. 1996).

Periodic, low-intensity surface fires, ignited by lightning and Native Americans, were common throughout many of the drier plant communities of the west prior to European settlement (Pyne 1982; Wright and Bailey 1982; Fiedler et. al. 1992; Agee 1993; Lewis 1993; Mutch and Cook 1996). These fires reduced forest densities, recycled nutrients, and stimulated the germination and growth of many plants. Under this historic fire regime plant communities were not only highly resilient to frequent disturbance but were also biologically diverse as a result of it (Wright and Bailey 1982; Agee 1994; Huff et al. 1995; Harrod et al. 1996). A century of timber harvesting, livestock grazing, and organized attempts at fire exclusion, combined with the relegation of Native Americans to Reserve lands thereby reducing fire ignitions, has resulted in high stand densities, reduced nutrient availability, and stagnant plant growth (Mutch 1993; Mutch et al. 1993; Sackett et al. 1996). Ecosystem diversity, when adapted to frequent disturbance, can lead to ecosystem homogeneity in the absence of it. Ecosystem resilience, or the ability to "bounce back" following a large-scale disturbance, can be greatly diminished (Rapport and Yazvenko 1996). These stressed and unhealthy ecosystems can support epidemic populations of insects and fungi (Schmid and Mata 1996) and are susceptible to high-intensity wildfire (Arno 1996b; Mutch and Cook 1996).

In order to better understand the historic stand conditions, and disturbance regimes that maintained these ecosystems research efforts have centered on conducting stand reconstruction and fire history studies (Fiedler 1996; Fiedler et al. 1996). Recent studies in Montana (Habeck 1990; Arno et al. 1995) and Arizona (Covington and Moore 1994; Gray and Wesley in press) indicate the extent to which these ecosystems have changed. Stand density, diameter distribution, species composition, and fire frequency targets can then be described to achieve the desired condition for these ecosystems (Fiedler et al. 1996).

This research approach is currently being applied to selected sites in the Interior Douglas-fir (IDF) and Ponderosa Pine (PP) biogeoclimatic zones (Meidinger and Pojar 1991) in the Rocky Mountain Trench area of southeastern British Columbia. Dry, low-elevation forests of ponderosa pine, Douglas-fir, and western larch in the Trench are exhibiting ecosystem health symptoms similar to nearby sites in the United States.

Because so much of these two forest types have been highly altered by various resource management activities over the last 150 years it's not possible to sample for fire history or historic stand characteristics by way of randomly located plots. Very few suitable stands remain in the Trench meaning as much sample location bias will have to be resolved with the sample design. A study conducted by Arno et al. (1995) in western Montana, where a similar lack of suitable study sites was encountered, utilized a large plot - 1 hectare in size - to incorporate as much site variability as possible in the sample. By following the author's procedures, as well as their sample design, a larger pool of data for ecologically similar forest types can be collected. The stand structure and fire history data from both B.C. and Montana can then be used to help guide and monitor ecosystem restoration efforts in B.C.

Forest health assessments and restoration initiatives are cited as investment priorities under the BC Forest Renewal Plan (Forest Renewal BC 1996).

3.0 OBJECTIVES

3.1 Stand Reconstruction Study

The stand reconstruction study objectives are: to describe the present forest structure; determine and describe the pre-European settlement[1] forest structure; and, to compare the two. Specific forest structure characteristics being

[1] The term "pre-European settlement" is used to describe the forest conditions prior to settlement by non-endemic people (Skovlin and Thomas 1995). The datum for pre-European settlement in the Rocky Mountain Trench will be 1850. As of that date no appreciable European settlement activities, outside of Catholic missionary work in 1846, had taken place in the Trench (Scott and Hanic 1979).

determined and described are: stand density, diameter distribution, and species composition. With the inclusion of the fire history data it may be possible to correlate periods of in-growth with fire events. Because the majority of study sites are classified as either IDFdm2 (Braumandl and Curran 1992) or transitional between IDFdm2 and PPdh2, pre-European settlement forest stand characteristics should be applicable to IDFdm2 ecosystems throughout the Trench.

3.2 Fire History Study

The fire history study objective is to determine the pre-settlement fire regime[2]. Analysis of cross-sectioned samples from fire-scarred trees yields the following information: the minimum fire-return interval (shortest time period between successive scarring fires); the maximum fire-return interval (longest time period between successive scarring fires); The mean fire-return interval (arithmetical average of all fire intervals); and the seasonality of fire occurrence (describes the propensity for fires to occur during certain seasons of the year; useful for determining fire causes) (Malanson 1987; Martin and Sapsis 1991).

A determination of how extensive fire regime data can be applied throughout the region will depend to a great extent on the results from each study site. If the majority of study sites are yielding similar pre-settlement stand structure information certain assumptions can be made regarding the fire regime that maintained those conditions. In many forested ecosystems age structure, species composition, and stand density are controlled by the ecosystem's fire regime (Kilgore 1978; Anderson and Brown 1986).

4.0 CHOOSING CANDIDATE STUDY SITES

4.1 Criteria for Ranking[3]

The criteria used in the ranking are as follows:

1. Disturbance history. Stands least affected by timber harvest and/or intensive wildfire or prescribed fire.

2. Vegetation classification. IDFdm2, IDFun, or PPdh2 in the lower elevation of the Rocky Mountain Trench within the Cranbrook and Invermere Forest Districts.

3. Topography. Areas of uniform topography large enough to accommodate a 1 ha plot (100m x 100m).

4. Size. Stands at least two hectares in size.

[2] The descriptive elements of a "fire regime" are: the minimum fire-return interval; maximum fire-return interval; mean fire-return interval; seasonality; and, dimensions (Martin and Sapsis 1991).
[3] In the event that available funds limit the number of sites to be studied, dropping sites off the end of the list will insure that only the best sites will be sampled.

5. Stand age. Oldest stands available (significant portion of stems >150 years old).

The suitability of each candidate study site was numerically ranked as part of the study site analysis component of this contract. The ranking is listed in Table 1.

It has become apparent from studies throughout the west that large, undisturbed stands of old growth ponderosa pine, Douglas-fir, and/or western larch are almost non-existent (Arno et al. 1995; Arno et al. [in press]; Quesnel 1996). Studies of fire history and the effects that historical fire regimes have had on stand characteristics have relied on whatever “remnant” stands were available. Because of this fact it is not possible to select sample areas using criteria that would ensure representativeness (Arno et al. 1995; Swetnam and Baisan 1996). Instead, sampling must be done where the evidence exists (Swetnam and Baisan 1996; S.F. Arno, pers. comm., Jan. 1997).

TABLE 1. Study site ranking based on criteria

Rank	Site Name	Disturbance	Biogeoclimatic Class.	Topography	*Size (ha)	Stand Age
1	Perry Creek	None	IDF dm2 03	uniform	71.5	>200
2	Premier Lake (Eastside)	None	IDF dm2 01	uniform	33.8	>150
3	Newgate	Some	IDF dm2 01	uniform	42.1	>150
4	Gold Creek	None	IDF dm2 02/PP dh2	uniform	44.8	>160
5	Premier Lake (Westside)	None	IDF dm2 01	uniform	17.4	>150
6	Lewis Ridge	None	IDF dm2 03/PP dh2	undulating	29.8	>250
7	Canal Flats	None	IDF dm2 01	undulating	123.7	>150
8	Grundy Creek	Some	IDF dm2 04	undulating	21.8	>170
9	Isidore Canyon	Some	IDF dm2 01/02	undulating	15.4	>200
10	Lower Lewis Creek	Some	IDF dm2 03/PP dh2	undulating	19.4	>130

* Stand size is indicated as gross forest polygon size, not suitable sampling size. For all of the study sites the suitable area is much less than the gross area.

5.0 METHODS

5.1 Field Methods

5.1.1 Stand reconstruction study

- Plot reconnaisance and site analysis. For each study site an initial reconnaisance will need to be made to locate the plot boundaries[4]. Plot location should take into consideration site uniformity, disturbances, aspect changes, and obstructions to surface fuel continuity. Because there are so few remnant stands from which to determine pre-settlement stand characteristics there are no standards for the maximum acceptable level of disturbance (S.F. Arno, pers. comm., Jan. 1997). In the case of past logging disturbance, Arno et al. (1995) substituted 3 similarly sized trees outside the plot for trees that had been cut inside the plot.
- Plots will be laid out accurately with a laser range finder (makes the job much easier), flagging tape and marking pins.
- A complete site identification including a soil profile will be done to provincial standards (outlined in MOE Manual 11: Describing Ecosystems in the Field).
- Plot traverse. A closed-loop traverse, using the contour line as the X-axis, and the slope line as the Y-axis, will be used for the plot boundary. Cartesian coordinates will be used for individual tree and tree clump (trees < 1.2 m tall) locations. The number of sighting locations along the traverse will be dependent on the density of trees in the plot.
- Gather overstory live tree data. Collect distance from plot boundary, azimuth, d.b.h., height, and species data for each overstory tree (trees greater than 150 years) in the plot. Collect increment cores at the base (30 cm) of each tree. Several increment cores should be taken until the pith is intersected or the core passes very near to it. For increment coring efficiency, it’s recommended that a power borer (Scott and Arno 1992) and 50 to 70 cm bits be used.

[4] In the case of Perry Creek and Premier Lake (eastside), the 2 largest and least disturbed sites, several plots could be located in the study stands. After systemmatically accepting/rejecting a sample location due to excessive tree mortality, type boundary, slope break, rock outcrop, etc., additional plots can be located in the stand. These additional plots could show some differences in stand characteristics, but they could also show many similarities. It should be noted however that it is the historic fire regime, the process that directed the pre-settlement stand characteristics, that is likely to show the least variation across the stand, not the stand characteristics (S.F. Arno, pers. comm., Jan. 1997).

- Gather understory (trees less than 150 years old, but greater than 1.2 m in height) live tree data. All isolated understory trees in 5 cm diameter classes will be mapped, and data collected on diameter, height, and species. Clumps of understory trees will be mapped by recording the coordinates of points around the perimeter of the group. Cross-sections will be taken at ground-level from random subsampling by species and diameter-class, to determine what age-classes are present.
- Gather dead-standing and dead-downed tree information. All dead-standing and dead-downed trees will be recorded by location, species and diameter. Diameters from dead-downed trees will only be collected from samples with recognizable bases. This data will be used in the reconstruction of the pre-settlement stand structure, not for assumptions of fuel or coarse woody debris loading.
- Storage of increment cores. All increment cores from understory trees are to be labeled, recorded on field forms, inserted into drinking straws, and stored in a dry, cool container. Understory cross-sections will be labeled, recorded and stored in dry, cool containers. All increment cores from overstory trees are to be mounted in the field on grooved panels. Field mounting (with water-soluble glue and wrapped with masking tape) prevents core shrinkage and helps to validate assessments of pre-settlement d.b.h. The tree number, location, species, and height of core will be recorded on the panel. Only the best corings from the d.b.h. and base corings need to be kept. Store all panels in a dry, cool container.

5.1.2 Fire history study

- Seek fire-scarred sample trees. Conduct a reconnaissance to locate 3-4 live trees at each site (Arno et al. 1995; Agee 1996; Arno et al. 1996). It is not expected that many (more than 3-4) useable samples will be located within the immediate vicinity of each of the plots. Find suitably scarred ponderosa pine, Douglas-fir, western larch, and lodgepole pine in that preference order. Also seek fire-scarred stumps and dead trees that are relatively free of decay. The composite fire history, however, cannot be constructed from dead samples only. In order to determine known fire years dead samples need to be cross-dated with live samples.
- Identify locations of scarred trees. Use Cartesian coordinates for sample trees located in the plot

and a Global Positioning System (G.P.S.) for trees outside the plot. The exact location of fire history samples can become part of a regional composite map of fire history data if subsequent research is conducted. Ensure that sample trees located outside of the plots are from the same vegetation type, topography, aspect, and fuel complex as the plot itself. Taking a fire scar sample from a tree that is isolated from the plot by a barrier to fire spread will yield inaccurate fire history results.

- Large-diameter trees (> 40 cm). It is recommended that fire scar sampling procedures detailed in Arno and Sneck (1977) be used for sample collection. Appendix 1 shows how fire scarred trees are to be sampled (from Arno and Sneck 1977). An altered version of the Arno and Sneck (1977) procedure is to cut a partial sample “wedge” out of the tree. In high visibility or administratively restrictive areas (parks, wilderness, etc.), cutting a small wedge that contains a subsampling of the fire record may be feasible where an entire sample may be restrictive. It should be noted that the more critical portions of the wedge are also the most fragile. Which ever procedure is followed the samples will be taped with duct tape across the catface section to prevent damage during transport and storage. Multiple pieces of the same sample should be marked along the break, identified, and packaged.
- Small-diameter trees (< 40 cm). Small diameter trees should be felled instead of trying to cut a partial cross-section out of them. The best fire-scar sample location on the bole may become apparent after several cross-sections have been removed. A 3 cm thick cross-section is sufficient. Samples will be taped with duct tape across the catface section to prevent damage during transport and storage. Multiple pieces of the same sample should be marked along the break, identified, and packaged.
- Data collection. Photograph each sample tree before and after cutting. Record all data as per the Laboratory of Tree-Ring Research (University of Arizona) procedures (Grissino-Mayer 1993). The data collection form displayed in Appendix 2 is designed to align with the fire chronology software.
- Storage and transport. Securely store all sample wedges and cross-sections and transport them in cool, dry containers.
- Treat wounded sample trees. Paint all open wounds with an asphalt-based tree paint to limit insect and fungal damage (Arno and Sneck 1977).

5.2 Laboratory Methods

5.2.1 Stand reconstruction study

- Core analysis. All core samples will be remounted in the lab into individual grooved, wooden holders and sanded either by hand or with an orbital sander. Sanding should begin with high grit (100) paper and followed with 400 grit polishing paper. Increment analysis can be done either manually with a high-powered binocular microscope and micrometer or with a Measur-Chron Distance Potentiometer. The advantage of using the poteniometer is the automation of the analysis. The core is moved along under the microscope by a hand crank, alleviating the problem of hand feeding the core under the microscope. All data collected from the core, increments and distances between increments, is automated and stored on computer similar to the ANNULUS system described by McCollum (1995). The alternative is to manually input the data after manually collecting it.
- Combine field data with laboratory data and perform analysis. Total specimen age and growth pattern information will be combined with the field data (species, d.b.h., height, location on the plot) into a database. From the database stand density, diameter distribution, mean d.b.h., gross standing volume, basal area, and species composition will be available for the present and the pre-settlement period. Rates of in-growth, their physical pattern, and any correlation with fire events (from the fire history study) will also be available. Data will be stored in database and spreadsheet formats and as a data layer in G.I.S. which can be plotted spatially.

5.2.2 Fire history study

- Dry fire scar samples and prepare. Fire scar samples will be air-dried for several weeks in a cool, dry environment. Samples should be placed upright on edge to exspose both cut surfaces to drying. This is done to prevent molding and to facilitate drying. Once dry, samples will be sanded with 60 or 100 grit sanding paper using an orbitol or belt sander. Sample finishing will be done with 400 grit paper. Care must be taken to not damage the char on the catface surface. Following sanding this surface should be cleaned with either a soft-bristle brush or compressed air.
- Fire scar data analysis. Under a high-powered microscope the first date marked on the samples from live trees (instructions for dead tree samples

follow) should be the last full increment year. Count and mark rings in groups of ten in descending order towards the pith marking the dates with a marking pen. When fire scars are located on the sample determine the last year in which a full increment was produced before any fire damage. The following ring will appear to be split by the scar; this is the year in which the fire occurred. Continue to collect increment and fire year data to the pith and tabulate on the Laboratory of Tree-Ring Research data sheet (Appendix 4). For a thorough description of the methodology see Arno and Sneck (1977).

- Fire scar seasonality analysis. To determine the seasonality of particular fires, very clear fire scar samples can be viewed under high magnification to reveal the cell structure at the edge of the fire scar (Appendix 3). Scars originating in early wood correspond to fires occurring in the spring and early summer. Those originating in the late wood correspond to late summer and early fall fires (Baisan and Swetnam 1990; Grissino-Meyer et al. 1994).
- Determine fire years from dead samples. Prepare dead samples the same as live samples. Identify all increments containing fire scars and crossdate (Fritts 1976) the increment patterns around the scars with the increment patterns from the live samples. It may become apparent that a specific climate-induced growth pattern and subsequent fire-scar will be found on all samples. If that is the case crossdating dead samples with live samples will be much easier.
- Compute fire chronology. Crossdate all fire years with increment patterns and known dates from all fire history samples from the same plot. Known fire years can then be plotted using the Laboratory of Tree-Ring Research master fire chronology model (Grissino-Mayer 1993) (see Appendix 5 for an example).

6.0 RESOURCES REQUIRED

6.1 Field

6.1.1 Equipment

Equipment Item Description	Estimated Cost
• Laser rangefinder (Laser Technologies Criterion 400)	• Sells for $7,000 US, but can be rented in Vancouver
• Stihl BT310 drill attachment	• $260.00 Cdn.
• Drill adapter to connect increment bore bits to drill	• Estimated at $450.00 Cdn.
• Haglof or Suunto extra-length bore bits	• $450 to $619 depending on size requested.
• Husqvarna 272 or Stihl 038 chainsaw	• $779 to $891
• Global Positioning System	• Rents for $750/month

6.1.2 Person Power

Task	Person Days/Plot	Comments
• Plot recconnaisance and traverse	2-6	Extensive brushing of site lines will be required at several sites.
• Stand data collection	12-20	High density sites should use at least a 4-6 person crew divided into 2 person teams (ie. tree-plotting, collecting overstory trees, etc.).
• Fire history	4-6	Suggest a 2 person team for safety reasons.

6.2 Laboratory

6.2.1 Equipment

Equipment Item Description	Estimated Cost
• Measur-Chron Distance Poteniometer	• Use free of charge at Pacific Forestry Center
• High-powered binocular microscopes	• Use free of charge at PFC
• GIS services to plot coordinate data in PC-ARCINFO or PAMAP	• $55/hour
• Orbital sander	• Starts at $55.00 at Home Depot

6.2.2 Person Power

Task	Person Days/Plot	Comments
• Stand data preparation and analysis	20-40	The range in person days/plot reflects the range of stand densities in the study sites.
• Fire history sample preparation and analysis	6-8	This range is depended on collecting 3-4 samples/plot.

7.0 SUMMARY REPORT

The summary report will include each of the following subjects: introduction; summary of field and laboratory procedures; results; interpretations and discussion; and recommendations.

7.1 Introduction

The introduction will briefly describe the issue (background) and the study objectives.

7.2 Summary of Field and Laboratory Procedures

Field and laboratory methods and procedures will be summarized. This does not require as much detail as in the study plan.

7.3 Results

Study results will be presented following the procedures and format developed by Arno et al. (1995).

7.4 Interpretations and Discussion

Interpretations and discussion will center on the applicability of the study results to the issues affecting the Rocky Mountain Trench. Study results will also be interpreted and discussed in the context of the larger-scale area of high fire frequency-adapted ecosystems in western North America.

7.5 Recommendations

Recommendations will be made for the operational application of the study results, additional studies that should be conducted, and the publication of the study results. The varied target audiences and extension methods used to reach those audiences will be identified.

8.0 WORK SCHEDULE

- It is suggested that 5 study sites be sampled in their entirety this year (1997), with the remaining 5 completed next year. This will provide an opportunity to gauge the time and resource requirements for all of the stages of the project as well as providing useful interim data that can further promote the project.

- Sampling can begin once access is available in the spring.
- There is a risk of promoting insect attacks on saw-injured sample trees. The risk comes primarily from the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (Amman and McGregor 1985; Furniss and Carolin 1992; Amman and Lindgren 1995). Since most new adults emerge between mid-July and early August (Amman and McGregor 1985), sampling in May and June may prevent some sample tree mortality.

APPENDIX 1. Fire Scar Sample Collection Techniques

(Arno and Sneck 1977)

APPENDIX 2: Fire Scar Specimen Field Form

APPENDIX 3: Fire Scar Seasonality Identification Chart

APPENDIX 4: Fire Scar Specimen Laboratory Form

APPENDIX 5: Example of a master fire chronology (Grissino-Meyer *et al*. 1994)

Literature Cited

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C.

Agee, J.K. 1994. Fire and weather disturbances in terrestrial ecosystems of the eastern Cascades. U.S. Dep. Agric. For. Serv. PNW-GTR-320, Portland, Oreg.

_________. 1996. Fire regimes and approaches for determining fire history. *In* The use of fire in forest restoration. C.C. Hardy and S.F. Arno (editors). U.S. Dep.Agric. For. Serv. INT-GTR-341, Ogden, Utah.

Amman, G.D., and M.D. McGregor. 1985. The beetle: behavior, biology, and life cycle. *In* Integrating management strategies for the mountain pine beetle with multiple-resource management of lodgepole pine forests. M.D. McGregor and D.M. Cole (editors). U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. INT-174, Ogden, Utah.

Amman, G.D. and B.S. Lindgren. 1995. Semiochemicals for management of mountain pine beetle: status of research and application. *In* Application of semiochemicals for management of bark beetle infestations - proceedings of an informal conference. S.M. Salom and K.R. Hobson (editors). U.S. Dep. Agric. For. Serv. INT-GTR-318, Ogden, Utah.

Anderson, R.C., and L.E. Brown. 1986. Stability and instability in plant communities following fire. *Amer. J. Bot*. 73(3):364-368.

Arno, S.F., and K.M. Sneck. 1977. A method for determining fire history in coniferous forests of the mountain west. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. INT-42, Ogden, Utah.

Arno, S.F.; Scott, J.H.; and M.G. Hartwell. 1995. Age-class structure of old-growth ponderosa pine/Douglas-fir stands and its relationship to fire history. U.S. Dep. Agric. For. Serv. Res. Pap. INT-RP-481, Ogden, Utah.

Arno, S.F.; Smith, H.Y.; and M.A. Krebs. [1996]. Old growth ponderosa pine and western larch stand structures: influences of pre-1900 fires and fire exclusion. Proposed INT Res. Pap.

Arno, S.F. 1996a. The seminal importance of fire in ecosystem management - impetus for this publication. *In* The use of fire in forest restoration. C.C. Hardy and S.F. Arno (editors). U.S. Dep.Agric. For. Serv. INT-GTR-341, Ogden, Utah.

_________. 1996b. The concept: restoring ecological structure and process in ponderosa pine forests. *In* The use of fire in forest restoration. C.C. Hardy and S.F. Arno (editors). U.S. Dep.Agric. For. Serv. INT-GTR-341, Ogden, Utah.

Baisan, C.H., and T.W. Swetnam. 1990. Fire History on a desert mountain range: Rincon Mountain Wilderness, Arizona, U.S.A. *Can. J. For. Res*. 20:1559-1569.

Braumandl, T.F., and M.P. Curran (compilers and editors). 1992. A field guide for site identification and interpretation for the NFR. B.C. Min. For. , Res. Branch, Land. Manage. Handb. No. 20. Victoria, B.C.

British Columbia Ministry of Environment, Lands, and Parks. 1990. Describing ecosystems in the field: MOE Manual 11. Victoria, B.C.

Covington, W.W. and M.M. Moore. 1994. Southwestern ponderosa pine forest structure - changes since Euro-American settlement. *J. For*. 92(1):39-47.

Fiedler, C.E., Arno, S.F., Carlson, C.E., and M.G. Harrington. 1992. Management prescriptions for restoring biodiversity in inland Northwest ponderosa pine-fir forests. *Nor. Env. J*. 8(1):211-213.

Fiedler, C.E. 1996. Silvicultural applications: restoring ecological structure and process in ponderosa pine forests. *In* The use of fire in forest restoration. C.C. Hardy and S.F. Arno (editors). U.S. Dep.Agric. For. Serv. INT-GTR-341, Ogden, Utah.

Fiedler, C.E., Arno, S.F., and M.G. Harrington. 1996. Flexible silvicultural and prescribed burning approaches for improving health of ponderosa pine forests. *In* Conference on adaptive ecosystem restoration and management: restoration of cordilleran conifer landscapes of North America. W.W. Covington and P.K. Wagner (editors). U.S. Dep. Agric. For. Serv. RM-GTR-278, Fort Collins, Colo.

Forest Renewal BC. 1995. Handbook, land based programs. Forest Renewal B.C., Victoria, B.C.

Fritts, H. C. 1976. Tree rings and climate. Academic Press, New York, N. Y.

Furniss, R.L. and V.M. Carolin. 1992. Western forest insects. U.S. Dep. Agric For. Serv. Misc. Pub. No. 1339, Washington, D.C.

Gray, R.W. and V. Wesley [1997] Reconciling traditional Apache and western natural resource management philosophies on the San Carlos Apache Reservation. *In* Proceedings of the 1996 Society of American Foresters National Conference, Albuquerque, N. Mex.

Grissino-Mayer, H. 1993. Analysis of fires from tree-rings. Computer program ver. 1.51, Laboratory of Tree-Ring Research, Univ. Ariz., Tucson, Ariz.

Grissino-Mayer, H.; Baisan, C.H.; and T.W. Swetnam. 1994. Fire history and age structure analyses in the mixed-conifer sprucefir forests of the Pinaleno Mountains, Southeastern Arizona. Laboratory of Tree-Ring Research, Univ. Arizona, Tucson, Ariz.

Habeck, J.R. 1990. Old-growth ponderosa pine-western larch forests in western Montana: ecology and management. *Nor. Env. J.* 6:271-292.

Harrod, R.J.; Gaines, W.L.; Taylor, R.J.; Everett, R.; Lillybridge, T., and J.D. McIver. 1996. Biodiversity in the Blue Mountains. *In* Search for a solution: sustaining the land, people and economy of the Blue Mountains. R.G. Jaindl and T.M. Quigley (editors). American Forests, Washington, D.C.

Huff, M.H., Ottmar, R.D., Alvarado, E., Vihnanek, R.E., Lehmkuhl, J.F., Hessburg, P.F., and R.L. Everett. 1995. Historical and current forest landscapes in eastern Oregon and Washington - Part II: Linking vegetation characteristics to potential fire behavior and related smoke production. U.S. Dep. Agric. For. Serv. PNW-GTR-355, Portland, Oreg.

Johnson, C.G.; Clausnitzer, R.R.; Mehringer, P.J., and C.D. Oliver. 1994. Biotic and abiotic processes of eastside ecosystems: the effects of management on plant and community ecology, and on stand and landscape vegetation dynamics. U.S. Dep. Agric. For. Serv. PNW-GTR-322, Portland, Oreg.

Kilgore, B.M. 1976. Fire in ecosystem distribution and structure: western forests and shrublands. *In* Proceedings of the Conference: Fire regimes and ecosystem properties. H.A. Mooney *et al*. (tech. coords.). U.S. Dep. Agric. For. Ser. GTR-WO26, Washington, D.C.

Kolb, T.E.; Wagner, M.R., and W.W. Covington. 1994. Concepts of forest health. *J. For*. 92(7):10-15.

Lewis, H.T. 1993. Patterns of Indian burning in California: ecology and ethnohistory. *In* Before the wilderness: environmental management by Native Californians. T.C. Blackburn and K. Anderson (editors). Ballena Press, Menlo Park, Calif.

Malanson, G.P. 1987. Diversity, stability, and resilience: Effects of fire regime. *In* The role of fire in ecological systems. L. Trabaud (editor). Academic Press, The Hague, The Netherlands.

Martin, R.E., and D.B. Sapsis. 1991. Fires as agents of biodiversity: pyrodiversity promotes biodiversity. *In* Proceedings of the symposium on biodiversity of Northwestern California, University of California, Berkeley, Calif.

Meidinger, D. and J. Pojar. 1991. Ecosystems of British Columbia. BC Min. For., Victoria, B.C.

Mutch, R.W. 1993. Forest health and productivity: fire interactions. Paper presented at the forest health and productivity concurrent session, 1993 SAF National Convention, Indianapolis, Ind.

Mutch, R.W.; Arno, S.F.; Brown, J.K.; Carlson, C.E.; Ottmar, R.D. and J.L. Peterson. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. U.S. Dep. Agric. For. Serv. PNW-GTR-310, Portland, Oreg.

Mutch, R.W. 1994. Fighting fire with prescribed fire: a return to ecosystem health. *J. For*. 92(11):31-33.

Mutch, R.W. and W.A. Cook. 1996. Restoring fire to ecosystems: methods vary with land management goals. *In* The use of fire in forest restoration. C.C. Hardy and S.F. Arno (editors). U.S. Dep. Agric. For. Serv. INT-GTR-341, Ogden, Utah.

Pyne, S.J. 1982. Fire in America: a cultural history of wildland and rural fire. Princeton University Press, Princeton, N.J.

Quesnel, H.J. 1996. Assessment and characterization of old-growth stands in the Nelson Forest Region. B.C. Min. For., Victoria, B.C. Tech. Rep. TR-013.

Quigley, T.M. 1992. Forest health in the Blue Mountains: social and economic perspectives. U.S. Dep. Agric. For. Serv. PNW-GTR-296, Portland, Oreg.

Rapport, D.J. and S.B. Yazvenko. 1996. Ecosystem distress syndrome in ponderosa pine forests. *In* Conference on adaptive ecosystem restoration and management: restoration of cordilleran conifer landscapes of North America. W.W. Covington and P.K. Wagner (editors). U.S. Dep. Agric. For. Serv. RM-GTR-278, Fort Collins, Colo.

Sackett, S.S., Haase, S.M., and M.G. Harrington. 1996. Lessons learned from fire use for restoring southwestern ponderosa pine ecosystems. *In* Conference on adaptive ecosystem restoration and management: restoration of cordilleran conifer landscapes of North America. W.W. Covington and P.K. Wagner (editors). U.S. Dep. Agric. For. Serv. RM-GTR-278, Fort Collins, Colo.

Schmid, J.M. and S.A. Mata. 1996. Natural variability of specific forest insect populations and their associated effects in Colorado. U.S. Dep. Agric. For. Serv. RM-GTR-275, Fort Collins, Colo.

Scott, D., and E. Hanic. 1979. East Kootenay chronicle. Mr. Paperback, Langley, B.C.

Scott, J.H., and S.F. Arno. 1992. Using a power increment borer to determine the age structure of old-growth conifer stands. *West. J. Appl. For*. 7(4):100-102.

Skovlin, J.M. and J.W. Thomas. 1995. Interpreting long-term trends in Blue Mountain ecosystems from repeat photography. U.S. Dep. Agric. For. Serv. PNW-GTR-315, Portland, Oreg.

Steele, R.; Williams, R.E.; Weatherby, J.C.; Reinhardt, E.D.; Hoffman, J.T., and R.W. Thier. 1996. Stand hazard rating for central Idaho forests. U.S. Dep. Agric. For. Serv. INT-GTR-332, Ogden, Utah.

Swetnam, T.W., and C.H. Baisan. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. *In* Fire effects in southwestern forests: Proceedings of the second La Mesa Fire symposium, U.S. Dep. Agric. For. Ser. RM-GTR-286, Fort Collins, Colo.

Tanaka, J.A.; Starr, G.L., and T.M. Quigley. 1995. Strategies and recommendations for addressing forest health issues in the Blue Mountains of Oregon and Washington. U.S. Dep. Agric. For. Serv. PNW-GTR-350, Portland, Oreg.

Williams, G.W. 1995. References on the American Indian use of fire in ecosystems. U.S. Dep. Agric. For. Serv. Pacific Northwest Region, Portland, Oreg.

Wright, H.A. and A.W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, New York, N.Y.